Surface Bidirectional Reflectance Distribution Function observed at global scale by POLDER/ADEOS

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Abstract. The spaceborne POLDER instrument presents the unique capability of sampling the surface Bidirectional Reflectance Distribution Function (BRDF) up to about 60° viewing angle for the full azimuth range of every point on Earth at 6 km resolution, when atmospheric conditions are favorable. This paper presents examples of BRDF signatures acquired at this resolution on several terrestrial biomes (desert, steppe, grassland, boreal forest, savanna, wetland). Well identified directional signatures for all azimuths are obtained and shown to be different for each biome. Specific directional effects in the hot spot and specular directions are well observed in the data.

Introduction

The measurement of the Bidirectional Reflectance Distribution Function (BRDF) of terrestrial surfaces has several purposes, including the correction for directional effects of time series of coarse resolution satellite data used for vegetation monitoring [Leroy and Roujean, 1994; Wu et al., 1995], land cover classifications [Bicheron et al., 1997; Hyman and Barnsley, 1997], albedo retrieval [Cabot and Dedieu, 1997; Wanner et al., 1997], and retrieval of leaf area index and other biophysical parameters by inversion of radiative transfer model [Li et al., 1995; Qi et al., 1995; Privette, 1996]. Of particular interest are the observations near the sun direction for vegetation structure analysis [Nilson and Kuusk, 1989] and in the specular (sun glint) direction for wetland discrimination [Vanderbilt et al., 1998].

The BRDF has been measured in the last decades using ground [Kimes, 1983; Deering et al., 1992] and airborne [Ranson et al., 1994; Leroy and Bréon, 1996] experiments. BRDF effects have been seen from space with AVHRR, in its vertical across-track plane of observation [Gutman, 1987; Roujean et al., 1992].

The POLDER (Polarization and Directionality of the Earth’s Reflectances) data provide the first opportunity to sample the BRDF of every point on Earth, for viewing zenith angles up to about 60°, and for the full azimuth range, at a spatial resolution of about 6 km. POLDER has provided 8 months of data between November 1996 and June 1997 onboard the polar orbiting sun synchronous ADEOS satellite. A second version of the instrument will be launched on the ADEOS-2 platform in mid-2000. The purpose of this paper is to illustrate the POLDER measurement capacity by presenting examples of BRDF signatures acquired by the instrument.

Data processing

All POLDER data are operationally geocoded, calibrated, cloud-screened and atmospherically corrected [Leroy et al., 1997; Bréon and Colzky, 1998]. The top of atmosphere and surface products are available to the scientific community. Cloud screening is made of several tests. The 763 and 765 nm channels, centered on an oxygen absorption band, are used to derive the pressure of the main reflector (clouds or surface). The algorithm analyzes also the polarized reflectance for scattering angles close to 140°, where liquid clouds show a large polarized reflectance. Then a test is made using the 443 nm band, based on the principle that clouds are much brighter than soil or vegetation in the blue.

If the pixel is recognized as cloudfree, a correction for stratospheric aerosols and absorbing gases (O_3, O_2 and H_2O) is applied. Similarly to oxygen pressure estimates, a differential absorption technique is used with the 865 and 910 nm channels to derive a water vapor content which serves as input in the atmospheric correction of reflectances. The ozone correction is made with TOMS/ADEOS data. A molecular scattering correction is applied. The aerosol optical depth and granulometry (Angström coefficient) are derived from the polarized radiance measurements. However, since this derivation is still in a preliminary validation phase, the results presented in this paper are based on reflectances which have not been corrected or filtered for the aerosol effects derived self consistently with POLDER data.
Figure 1. Time series of surface reflectances at 443, 670, and 865 nm, for a pixel corresponding to a savanna site in Chad (9.47°N, 17.00°E).

Results

The reconstruction of the BRDF of a particular pixel from time series of surface reflectance is illustrated in Figures 1 and 2 for a savanna pixel located in Chad. A time period with a sufficient number of clear days is first selected. The first 15-day period of the time series displayed in Figure 1 has been used to produce the BRDF shown in directional space in Figure 2. The dozen of directional measurements per orbit appear as vertical series of dots in Figure 1, and as data points aligned in top left - bottom right directions in Figure 2. Figure 2 illustrates the directional configuration of the data set.

The BRDF results of six sites of different biomes: desert, steppe, grassland, boreal forest, savanna, and wetland, are shown in Figure 3 in the blue, red, near infrared. To facilitate the BRDF intercomparison, only sections of the BRDF in the principal plane (the 0° – 180° azimuth line in Figure 2) and the perpendicular plane (the 90° – 270° azimuth line) are represented. The data points of Figure 3 belong to 16°-wide bands of directional space, shown as gray areas in Figure 2. Fitted polynomial curves are superimposed to the data points to outline the general shape of the directional signatures. They are designed to be symmetric about the origin in perpendicular plane, and, in the principal plane, to fit the data located on each side of the data point closest to the sun direction. The site characteristics (biome, location, selected period, number of cloud free orbits, range of sun angle variations within this period) are reported in Table 1. In addition, Table 1 displays the smallest available angles between viewing direction and the sun and specular directions.

Figure 3 shows that both the spectral and directional signatures are quite variable from one biome to another. The desert site appears nearly Lambertian. The steppe and grassland sites are very similar spectrally, but the forward scattering components of their principal planes differ markedly. A local maximum around the so-called hot spot direction (where sun and view directions coincide) is a prominent feature of all signatures, but its shape is variable. The description of the peak depends on directional sampling. It is particularly high and well observed for the boreal forest and savanna cases, for which the smallest an-

Table 1. Sites and measurements characteristics

<table>
<thead>
<tr>
<th>Biome</th>
<th>Lat (°)</th>
<th>Long (°)</th>
<th>Country</th>
<th>Period</th>
<th>Cloud free orbits</th>
<th>Sun zenith range</th>
<th>Smallest angle to sun</th>
<th>Smallest angle to specular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert</td>
<td>23.36 N</td>
<td>21.76 E</td>
<td>Lybia</td>
<td>Nov 14 - Nov 29</td>
<td>13</td>
<td>43° - 50°</td>
<td>3.2°</td>
<td>4.3°</td>
</tr>
<tr>
<td>Steppe</td>
<td>32.53 N</td>
<td>106.44 W</td>
<td>USA</td>
<td>May 28 - Jun 23</td>
<td>16</td>
<td>9° - 25°</td>
<td>4.9°</td>
<td>3.6°</td>
</tr>
<tr>
<td>Grassland</td>
<td>42.75 N</td>
<td>112.40 E</td>
<td>Mongolia</td>
<td>May 28 - Jun 23</td>
<td>14</td>
<td>20° - 28°</td>
<td>4.9°</td>
<td>5.5°</td>
</tr>
<tr>
<td>Boreal forest</td>
<td>54.64 N</td>
<td>104.88 W</td>
<td>Canada</td>
<td>May 31 - Jun 12</td>
<td>14</td>
<td>31° - 36°</td>
<td>1.7°</td>
<td>6.8°</td>
</tr>
<tr>
<td>Savanna</td>
<td>21.08 S</td>
<td>21.40 E</td>
<td>Botswana</td>
<td>Dec 14 - Jan 3</td>
<td>14</td>
<td>10° - 31°</td>
<td>0.6°</td>
<td>3.0°</td>
</tr>
<tr>
<td>Wetland</td>
<td>23.75 S</td>
<td>46.34 E</td>
<td>Madagascar</td>
<td>Nov 4 - Nov 24</td>
<td>13</td>
<td>11° - 28°</td>
<td>2.7°</td>
<td>0.5°</td>
</tr>
</tbody>
</table>
A peak is clearly seen in the specular direction for the wetland site. This peak is an unambiguous indicator of the presence of water at the surface. This presence could not have been detected from the rest of the BRDF at all wavelengths. The peak size (low at 443 nm, intermediate at 865 nm, high at 670 nm) increases as the angle between view and specular directions decreases (1.2°, 0.9°, and 0.5° for 443, 865, and 670 nm, respectively). Assuming spectrally flat reflection on water, these figures that the peak is quite narrow, with a width on the order of 1° – 2°.
The directional signal is clear in all cases, that is, it is significantly larger than noise. The noise magnitude may be estimated in Figure 3 by looking at the scattering of data points around the polynomial curves. Part of the noise is only apparent and comes from the fact that the directional configurations are not quite comparable, either because the data points do not belong strictly to the principal/secondary planes, or because of variations of sun zenith angle between orbits. Another part of the noise is real and is attributed to variations of atmospheric conditions between days of observation, related to aerosol events and/or partial cloudiness not accounted for by atmospheric corrections. The signal to noise ratio should degrade if these latter effects become significant. Note that the apparent noise is very weak in the desert case, where the atmosphere is presumably very stable. It is also very weak for data points belonging to the same orbits (Figure 2), and also for the perpendicular plane of the savanna site (Figure 3), which happens to be made of the data points of a single orbit.

Summary

This paper has shown through illustrative examples on various biome types that the POLDER data permit reconstruction of the surface BRDF at the pixel resolution, for the full azimuth range and up to about $60^\circ$ view zenith angle, when atmospheric conditions are favorable. Clear directional signatures for all azimuths are obtained. Specific directional effects in the hot spot and specular directions are well observed in the data.

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References


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